

CLAIMS

1. Optical system for detecting the concentration of gaseous species, comprising at least one source of ultraviolet and/or visible radiation and a photodetector device opposite that source, between which there flows a gaseous mixture, characterised in that the said photodetector device comprises an active material based on gallium nitride (GaN), aluminium nitride (AlN) or indium nitride (InN) and corresponding alloys and is adapted to detect the concentration of the gaseous species present in the mixture through detecting the spectrum emitted by the said source modified through the combined absorption and emission effect of the said gaseous species.

2. Optical system according to Claim 1, characterised in that spectral discrimination of the various absorption lines is effected by selecting the active material from gallium nitride (GaN), aluminium nitride (AlN), indium nitride (InN) and corresponding alloys to selectively increase or reduce the absorption in specific spectral regions having wavelengths lying between 200 nm and 500 nm.

3. Optical system according to Claim 1, characterised in that spectral discrimination of the different absorption lines is effected by engineering the electronic band structure of the photodetector device, that is by alternating layers of different materials so as to form quantum wells.

4. Optical system according to Claim 1, characterised in that spectral discrimination of the different absorption lines is effected by engineering the photonic band structure of the photodetector device, that is by permitting only specific photon transitions through constructing photonic crystal optical microresonators.

5. Optical system according to any of the preceding claims, characterised in that the active material comprising the photodetector device is massive gallium nitride for the detection of spectral lines having a wavelength of 360 nm or higher.

6. Optical system according to any of Claims 1 to 4, characterised in that the active material comprising the photodetector device is gallium aluminium nitride ( $\text{Al}_x\text{Ga}_{1-x}\text{N}$  with  $0 \leq x \leq 1$ ) for the detection of spectral lines having a wavelength varying between 206 nm and 360 nm as  $x$  varies.

7. Optical system according to any of Claims 1 to 4, characterised in that the active material comprising the photodetector device is gallium indium nitride ( $\text{In}_x\text{Ga}_{1-x}\text{N}$ , with  $0 \leq x \leq 1$ ) for the detection of spectral lines having a wavelength varying between 360 nm and 500 nm as  $x$  varies.

8. Optical system according to any of Claims 1 to 4, characterised in that the active material comprising the photodetector device includes quantum wells of GaN/AlGaIn or InGaIn/GaN.

9. Optical system according to Claim 5, characterised in that the said photodetector device having massive GaN active material is produced through the stages of:

provision of a substrate,

growth of a nucleation layer of GaN on the said substrate in a  $\text{N}_2$  environment, with a feed of controlled flows of gaseous ammonia ( $\text{NH}_3$ ) and trimethylgallium (TMGa) growth precursors,

annealing heat treatment of the nucleation layer in a  $\text{N}_2$  and  $\text{NH}_3$  environment,

deposition of the active material in a  $\text{H}_2$  environment through vapour phase epitaxial growth with a feed of controlled flows of growth precursors,

provision of metal contacts on the structure through photolithographic processes and deposition by thermal evaporation and/or by an electron beam.

10. Optical system according to Claim 6, characterised in that the said photodetector device with massive AlGa<sub>N</sub> active material is produced through the stages of:

provision of a substrate,

growth of a nucleation layer of AlGa<sub>N</sub> on the said substrate in a N<sub>2</sub> environment, with a feed of controlled flows of gaseous ammonia (NH<sub>3</sub>), trimethylgallium (TMGa) and trimethylaluminium (TMAI) growth precursors,

annealing heat treatment of the nucleation layer in a N<sub>2</sub> and NH<sub>3</sub> environment,

deposition of the active material in a H<sub>2</sub> environment through vapour phase epitaxial growth with a feed of controlled flows of growth precursors,

provision of metal contacts on the structure through photolithographic processes and deposition by thermal evaporation and/or from an electron beam.

11. Optical system according to Claim 7, characterised in that the said photodetector device having massive InGa<sub>N</sub> active material is produced through the stages of:

provision of a substrate,

growth of a nucleation layer of InGa<sub>N</sub> on the said substrate in a N<sub>2</sub> environment, with a feed of controlled flows of gaseous ammonia (NH<sub>3</sub>), trimethylgallium (TMGa) and trimethylindium (TMIn) growth precursors,

annealing heat treatment of the nucleation layer in a N<sub>2</sub> and NH<sub>3</sub> environment,

deposition of the active material in a H<sub>2</sub> environment through vapour phase epitaxial growth with a feed of controlled flows of growth precursors,

provision of metal contacts on the structure through photolithographic processes and deposition by thermal evaporation and/or from an electron beam.

12. Optical system according to Claim 8, characterised in that the said photodetector device with active material comprising quantum wells formed of alternating layers of GaN/AlGa<sub>N</sub> is produced through the stages of:

provision of a substrate,

growth of a nucleation layer of GaN on the said substrate in a N<sub>2</sub> environment, with a feed of controlled flows of gaseous ammonia (NH<sub>3</sub>) and trimethylgallium (TMGa) growth precursors,

annealing heat treatment of the nucleation layer in a N<sub>2</sub> and NH<sub>3</sub> environment,

deposition of the active material in a H<sub>2</sub> environment through vapour phase epitaxial growth with a feed of controlled flows of growth precursors, including:

a) growth of a buffer layer of GaN,

b) growth of a barrier layer of AlGa<sub>N</sub>,

c) growth of a quantum well layer of GaN with a thickness depending on the spectral line which has to be detected and the aluminium content of the barrier layer,

d) repetition of b) and c) steps through a number of times equal to the predetermined number of quantum wells in order to obtain a predetermined degree of responsiveness from the optical sensor,

provision of metal contacts on the structure through photolithographic processes and deposition by thermal evaporation and/or from an electron beam.

13. Optical system according to Claim 8, characterised in that the said photodetector device having an active material comprising quantum wells formed by alternating layers of GaN/InGa<sub>N</sub> is produced through the stages of:

provision of a substrate,

growth of a nucleation layer of GaN on the said substrate in a N<sub>2</sub> environment, with a feed of controlled flows of gaseous ammonia (NH<sub>3</sub>) and trimethylgallium (TMGa) growth precursors,

annealing heat treatment of the nucleation layer in a  $N_2$  and  $NH_3$  environment,

deposition of the active material in a  $H_2$  environment through vapour phase epitaxial growth with a feed of controlled flows of growth precursors, including:

- a) growth of a buffer layer of GaN,
- b) growth of a barrier layer of InGaN,
- c) growth of a quantum well layer of GaN with a thickness depending on the spectral line which has to be detected and the indium content of the barrier layer,

- d) repetition of b) and c) steps through a number of times equal to the predetermined number of quantum wells to obtain a predetermined degree of responsiveness from the optical sensor,

provision of metal contacts on the structure through photolithographic processes and deposition by thermal evaporation and/or from an electron beam.

14. Optical system according to any of Claims 5 to 8, characterised in that the said active material is inserted into a device which has co-planar metal-semiconductor-metal contacts.

15. Optical system according to any of Claims 5 to 8, characterised in that the said active material has a heterostructure with a p-i-n structure.

16. Optical system according to any of Claims 5 to 8 dependent upon Claim 4, characterised in that the photonic crystal microresonator device has a vertical cavity structure for the selection of a single atomic absorption line produced during a stage of epitaxial growth including a central waveguide region containing the absorbent material inserted between two Bragg-type reflectors.

17. Optical system according to Claim 16, characterised in that the said photodetector device having a resonating cavity structure is produced through the stages of:

providing a substrate,

growth of a nucleation layer of GaN on the said substrate in a  $N_2$  environment, with a feed of controlled flows of gaseous ammonia ( $NH_3$ ) and trimethylgallium (TMGa) growth precursors,

annealing heat treatment of the nucleation layer in a  $N_2$  and  $NH_3$  environment,

deposition through vapour phase epitaxial growth with a feed of controlled flows of growth precursors, including:

a) growth of a buffer layer of GaN,

b) growth of a layer of aluminium nitride (AlN) having a lower refractive index, and a thickness of  $\lambda/4n_{AlN}$ , where  $\lambda$  is the design wavelength and  $n_{AlN}$  is the refractive index of aluminium nitride,

c) growth of a layer of gallium nitride having a higher refractive index and a thickness of  $\lambda/4n_{GaN}$ , where  $\lambda$  is the design wavelength and  $n_{GaN}$  is the refractive index of gallium nitride,

d) repetition of steps b) and c) for a predetermined number of pairs of layers having different refractive indices so as to form a first Bragg reflector,

e) growth of a layer of gallium nitride forming a resonant cavity, with a thickness of  $\lambda/n_{GaN}$  or a whole multiple of  $\lambda/2n_{GaN}$ ,

f) repetition of stages b) and c) for a predetermined number of pairs of layers having different refractive indices so as to form a second Bragg reflector,

provision of metal contacts on the structure through photolithographic processes and deposition by thermal evaporation and/or from an electron beam.

18. Optical system according to any of Claims 5 to 8, characterised in that the photodetector device has a structure based on two-dimensional photonic crystals.

19. Optical system according to Claim 18, characterised in that the said structure is produced through the following steps:

deposition of resist,

production of a predetermined photonic crystal pattern by direct writing by lithography from a high resolution electron beam and/or optical lithography,

transfer of the pattern to produce a cavity matrix in the active material, or columns matrix of active material, with a periodicity and diameter depending on the spectral line which has to be detected.

20. Optical system according to any of the preceding claims, characterised in that it comprises a matrix of photodetector devices which can be controlled independently and which operate at different spectral frequencies.

21. System for controlling a combustion process in a motor vehicle internal combustion engine, comprising an optical system for detecting the concentration of gaseous species in accordance with Claims 1 to 20.

22. Control system according to Claim 21, in which the said system for detecting the concentration of gaseous species includes heating means adapted to stabilise and maintain a predetermined operating temperature in the photodetector device to encourage the decomposition of unburnt residues and prevent the deposition of carbonaceous and non-carbonaceous residues.